

Forecourt Storage and Compression Options

> **DOE Annual Merit Review and Peer Evaluation**

Arlington, VA
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Gas Technology Institute

PDP 19

Overview

> Timeline

- Phase 1: June 2005 to February 2006
- Phase 2: TBD

> Budget

- Phase 1: \$150 K (\$100 K limit through Feb '06)
- Phase 2: \$818 K

> Barriers addressed

- 3.2.4.2 F: Hydrogen Delivery Infrastructure Storage Costs
- 3.2.4.2 H: Storage Tank Materials and Costs

> Partners

- Phase 1: None
- Phase 2: TBD

Objectives

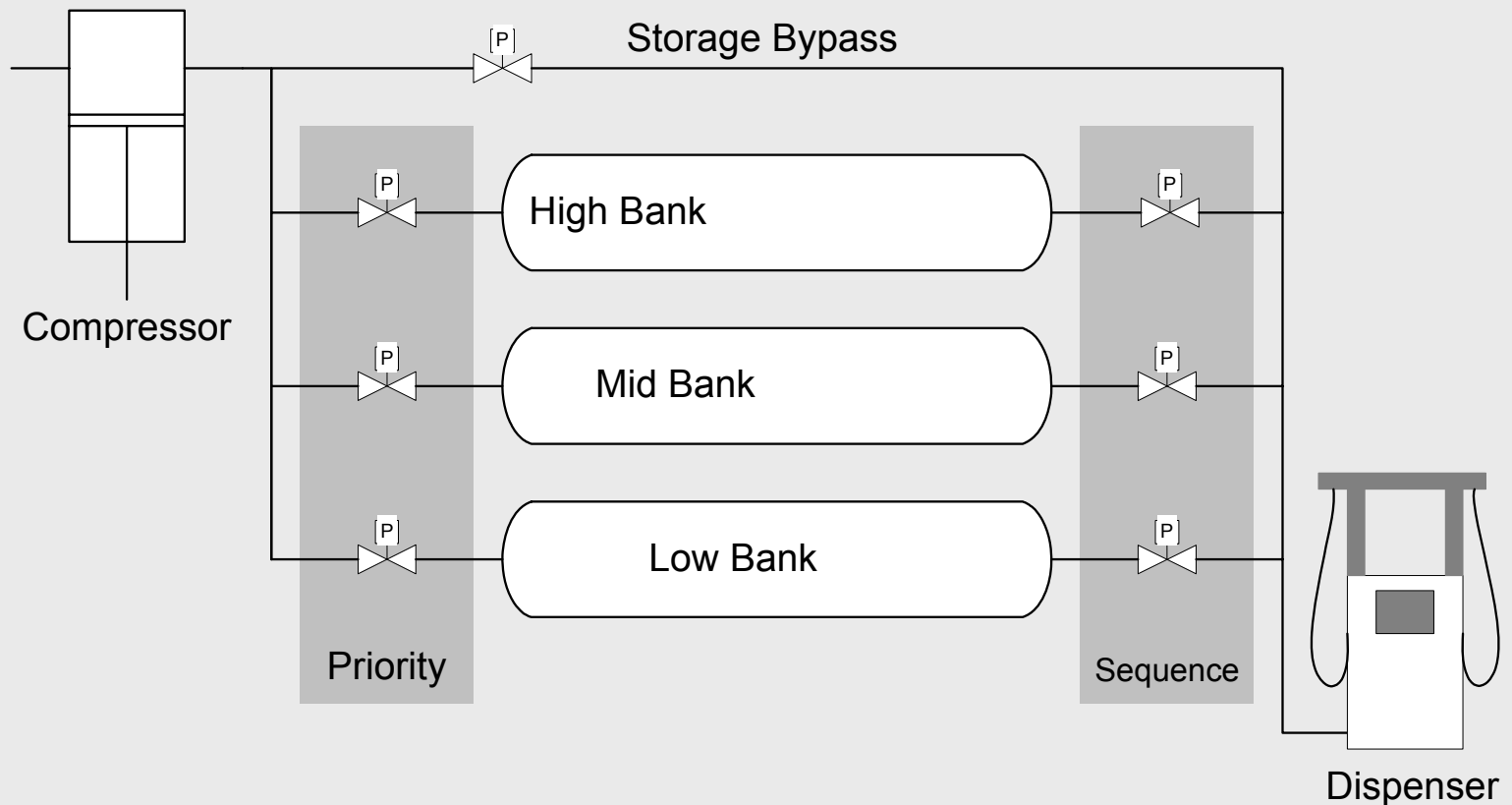
- > Examine technical feasibility and cost implications of a wide variety of forecourt compression and storage configurations

Approach

- > Update station sizing software tool
 - Allow for a wider variety of station configurations
- > Equipment cost data collection
- > Perform economic analyses
- > Examine additional tradeoffs
 - Cryo pump vs. compressor
 - Under ground vs. above ground
 - Advanced composites vs. steel

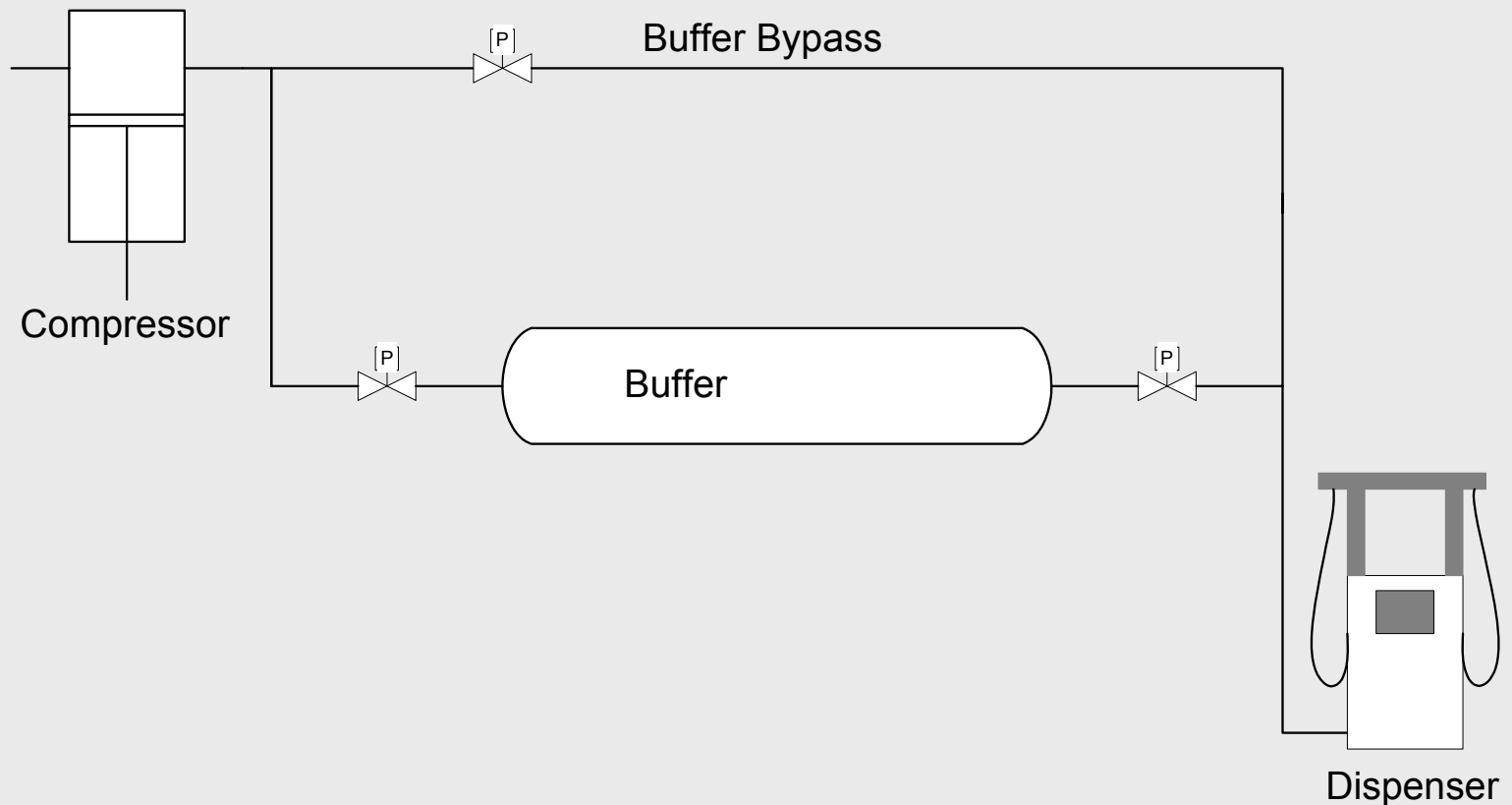
Station Configuration: Cascade Fill

- > Uneven demand from smaller vehicles
- > Sporadic demand from larger vehicles



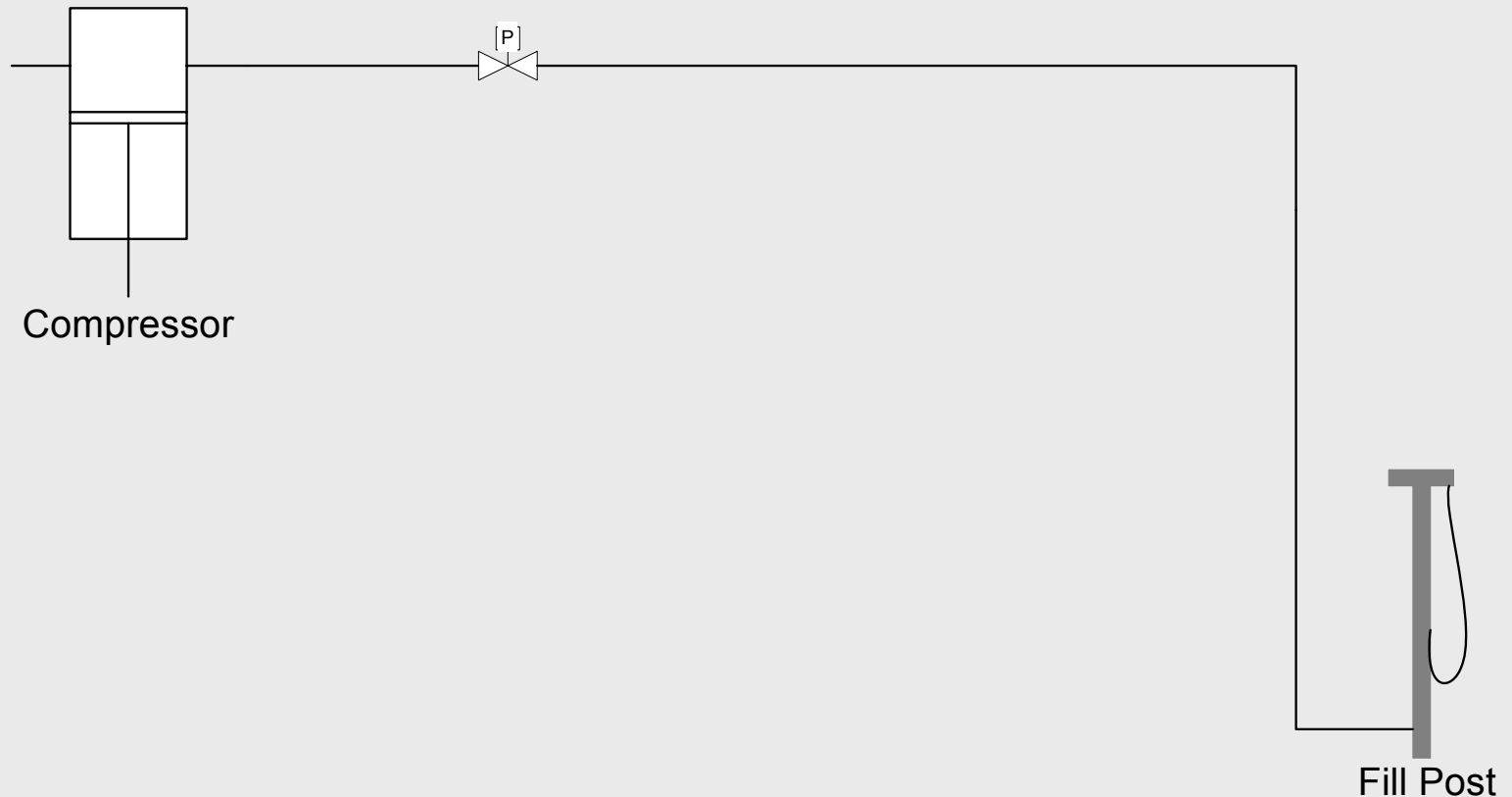
Station Configuration: Buffer Fill

- > Large vehicles fueling continuously
- > Most fueling directly from compressor(s)



Station Configuration: Time Fill

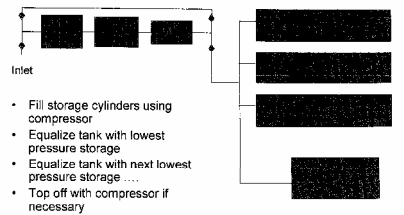
- > Vehicles return to property for several hours
- > Total fill cycle will usually requires 8+ hours



Other Potential Configurations

Fueling Strategies

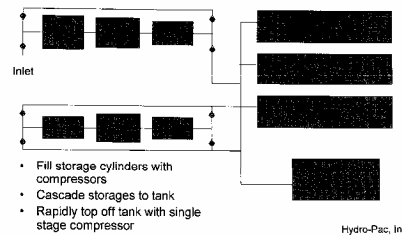
Cascade Fill – With Multi-Stage Compressor and Multiple Storage Cylinders



Hydro-Pac, Inc.

Fueling Strategies

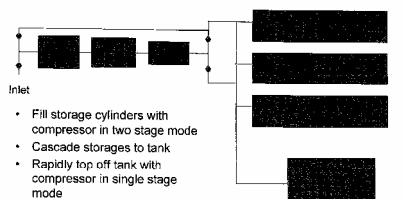
Rapid Fill – With Multiple Intensifiers and Multiple Storage Cylinder



Hydro-Pac, Inc.

Fueling Strategies

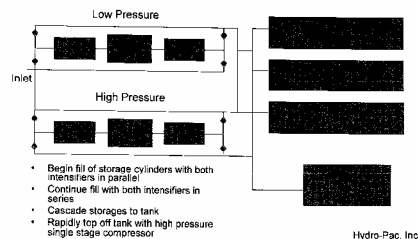
Rapid Fill – With Hybrid Intensifier and Multiple Storage Cylinders



Hydro-Pac, Inc.

Fueling Strategies

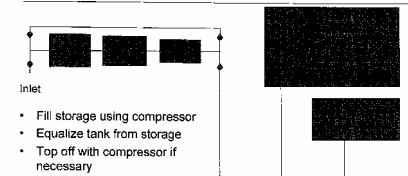
Rapid Fill – With Two Single Stage Intensifiers in parallel and/or Series



Hydro-Pac, Inc.

Fueling Strategies

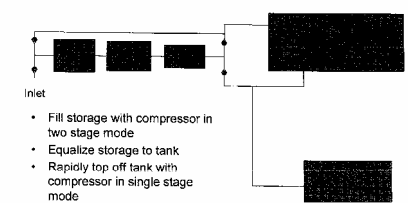
Slow Fill – With Multi-Stage Compressor and Large Storage



Hydro-Pac, Inc.

Fueling Strategies

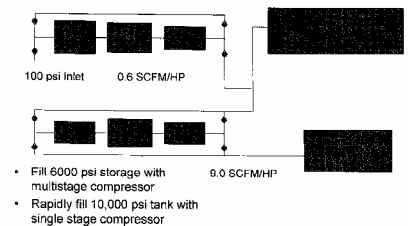
Rapid Fill – With Hybrid Intensifier and Single Storage



Hydro-Pac, Inc.

Fueling Strategies

High Pressure Fill – With Medium Pressure Storage



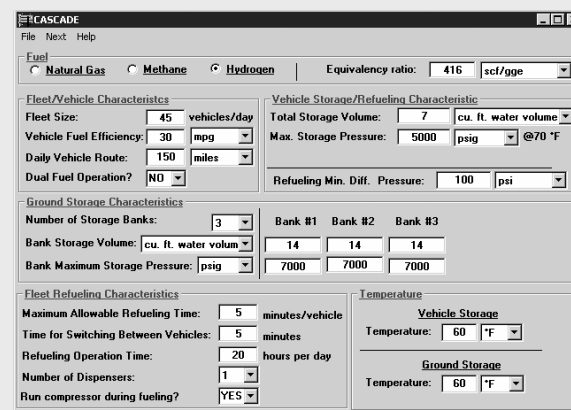
Hydro-Pac, Inc.

Hydrogen Station Sizing: CASCADE H2

- > Simulate compressed gaseous fuel station operation
 - Facilitates quick system sizing and tradeoff analysis
 - System compression and storage sizing
 - Matching station fuel supply to demand
 - Models peak fuel demand periods
 - Helps minimize capital costs and maximize utilization



NATURAL GAS & HYDROGEN
FUELING STATION SIZING



The screenshot shows the CASCADE software interface with the following settings:

- Fuel:** Natural Gas (selected), Methane, Hydrogen
- Equivalency ratio:** 416 scf/gge
- Fleet/Vehicle Characteristics:**
 - Fleet Size: 45 vehicles/day
 - Vehicle Fuel Efficiency: 30 mpg
 - Daily Vehicle Route: 150 miles
 - Dual Fuel Operation?: NO
- Vehicle Storage/Refueling Characteristics:**
 - Total Storage Volume: 7 cu. ft. water volume
 - Max. Storage Pressure: 5000 psig @70 °F
 - Refueling Min. Diff. Pressure: 100 psi
- Ground Storage Characteristics:**
 - Number of Storage Banks: 3
 - Bank Storage Volume: cu. ft. water volume
 - Bank Maximum Storage Pressure: psig
 - Bank #1: 14, 7000; Bank #2: 14, 7000; Bank #3: 14, 7000
- Fleet Refueling Characteristics:**
 - Maximum Allowable Refueling Time: 5 minutes/vehicle
 - Time for Switching Between Vehicles: 5 minutes
 - Refueling Operation Time: 20 hours per day
 - Number of Dispensers: 1
 - Run compressor during fueling?: YES
- Temperature:**
 - Vehicle Storage: 60 °F
 - Ground Storage: 60 °F

CASCADE H2 PRO

Enhancements

- > Improved system flow representation
- > Multiple, simultaneous vehicle fueling
- > User selectable maximum dispenser flow rate
- > Multiple vehicle types and flexible scheduling
- > User definable compressor characteristics
 - Power consumption, volumetric efficiency
- > Compressor electric power and demand calculation
 - Time of day and seasonal rates
- > Station life cycle cost analysis
- > Improved charting and reporting features

CASCADE H2 PRO Inputs

- > Variable configuration parameters
 - Vehicles (type and quantity), storage capacities and pressures, dispensers, peak flow
- > Variable cost elements
 - Peak and off peak electricity (seasonally), time dependent costs (per year), usage dependent costs (per kg)
 - Economic life, cost of capital, taxes, inflation, depreciation methods

CASCADE H2 PRO File: C:\Burn Folder\cascade tests\DOEm1.mdb

File Unit: I-P (English) Next Help

Vehicle Storage/Refueling Characteristic

A	B	C	D
Total Storage Volume:	8.5	cu. ft. water volume	Vehicle Description: Description for A..
Rated Storage Pressure:	5075	psig @ 59°F	
Max. Allowable Storage Pressure:	6344	psig	
Min. Allowable Storage Pressure:	50	psig	
Capacity Before Refueling:	12.5	% of Full	

Ground Storage Characteristics

Number of Storage Banks: 3

	Bank #1	Bank #2	Bank #3
Bank Storage Volume: cu. ft. water volume	30	20	10
Bank Maximum Storage Pressure: psig @ 59°F	7000	7000	7000

Fueling Station Characteristics

Time for Switching Between Vehicles: 3 minutes

Dispenser Rating Point Pressure: 7000 psig

Dispenser Rating Point Flow Rate: 8 lb/min

Dispenser Min. Diff. Pressure: 100 psi

Number of Dispensers: 2

Run compressor during fueling? YES

Edit Station Load Profile / Schedule

Unit Selection

☒ I-P (English)
☐ SI (Metric)

Fuel

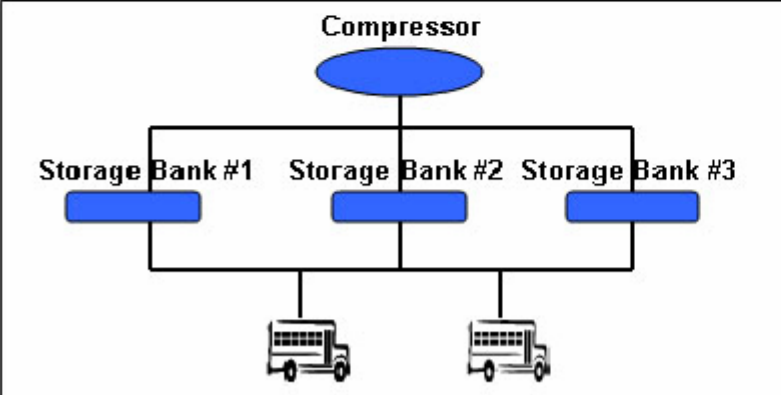
Hydrogen

Equivalency ratio: 416 scf/gge

Temperature

Vehicle Storage
59 °F

Ground Storage
59 °F



Fueling with 3 storage banks.

Help Next

Economic Analysis

Electric Rates

Summer

Starts:

	From	Hour	To	Rates
Demand On Peak	9:00		17:00	14.24 \$/kW
Energy On Peak	9:00		17:00	0.05022 \$/kWh
Energy Off Peak				0.02123 \$/kWh

Tax: %

Winter

Starts:

	From	Hour	To	Rates
Demand On Peak	9:00		17:00	11.33 \$/kW
Energy On Peak	9:00		17:00	0.05022 \$/kWh
Energy Off Peak				0.02123 \$/kWh

Life Cycle Parameters

Study Period: years

Depreciation Period: years

Finance Period: years

% Financed: %

Fin. Interest Rate: %

Cost of Capital: %

Tax Rate: %

Inflation Rate

Electric Rates: %

H2 Costs: %

O_M Costs: %

Depreciation Book Method

☒ SL ☐ DDB ☐ SUM

Depreciation Tax Method

☐ SL ☒ DDB ☐ SUM

Economics

Available Equipment:

- Compressor - Equip1
- Equip1
- Equip2
- Other
- Install

Station Equipment:

- Compressor - Equip1
- Equip1
- Equip2
- Other
- Install

Buttons: Add --> <-- Remove Add New -->

Compressor - Equip1

Installed Cost, \$:

O_M Cost:

Fix: \$/year

Variable: \$/lb

Edit / View

Annual Electric Consumption, kwh:

Annual H2 Consumption, lb:

Annual Fix Salary Cost, \$:

Total Installed Cost, \$:

Annual O_M Cost, \$:

H2 Rates

Cost: \$/lb

Tax: %

Sell Price: \$/lb

IRR Optimization

Target of Internal Rate of Return, %:

Sell Price: \$/lb

Calculate Sell Price

Results

Net Present Value*, \$

Simple Payback, year

Internal Rate of Return, %

Life Cycle Payback, year**

* Life cycle present value cumulative cash flow.

** Years needed to achieve positive present value cumulative cash flow.

Calculate Report Cancel Done

CASCADE H2 Pro Results

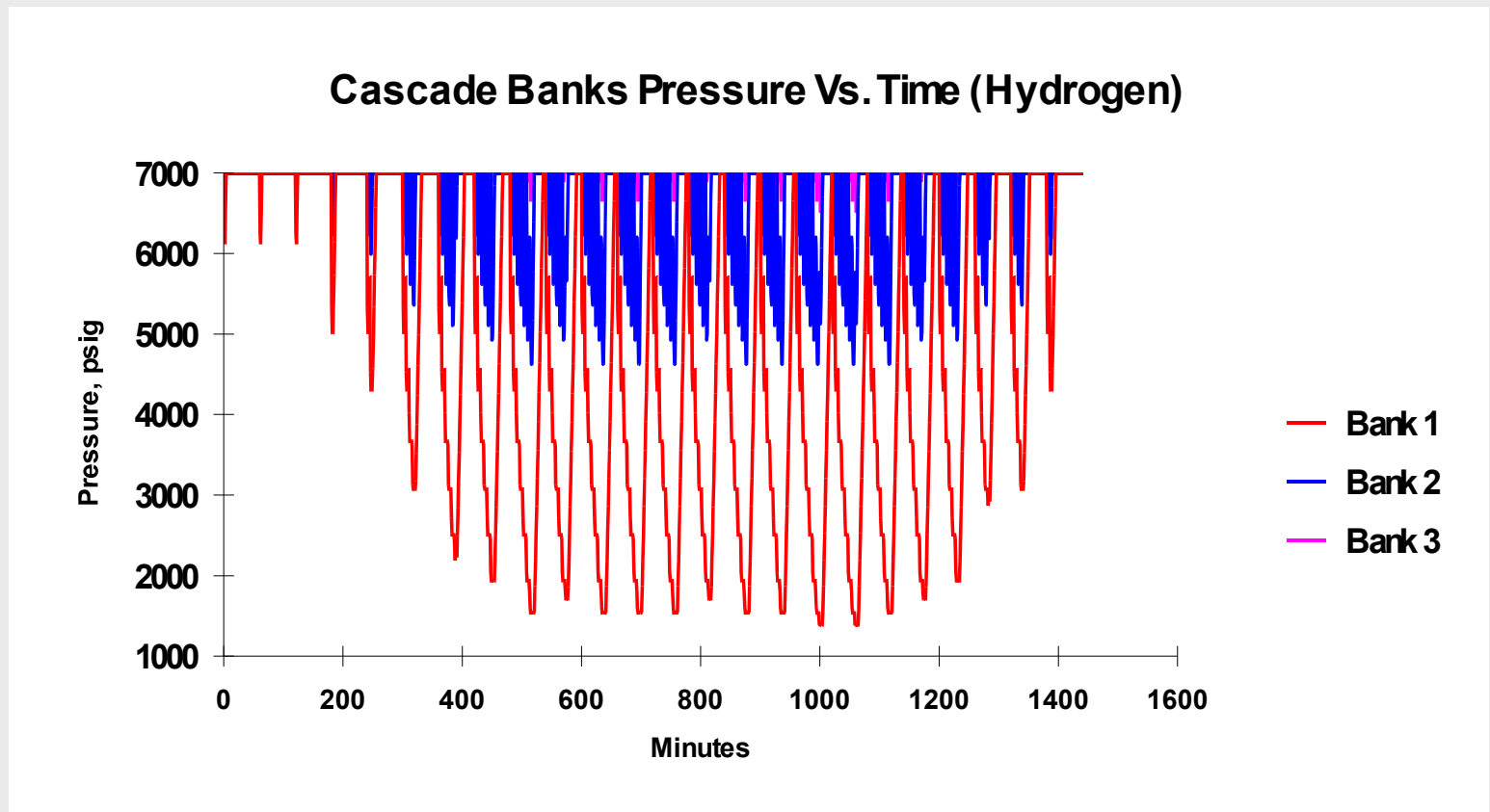
> Performance

- Cascade pressure, capacity
- Compressor output, power, electric demand
- Station and dispenser load profiles
- Vehicles fully served (or not), maximum fill pressure, filling times

> Economic

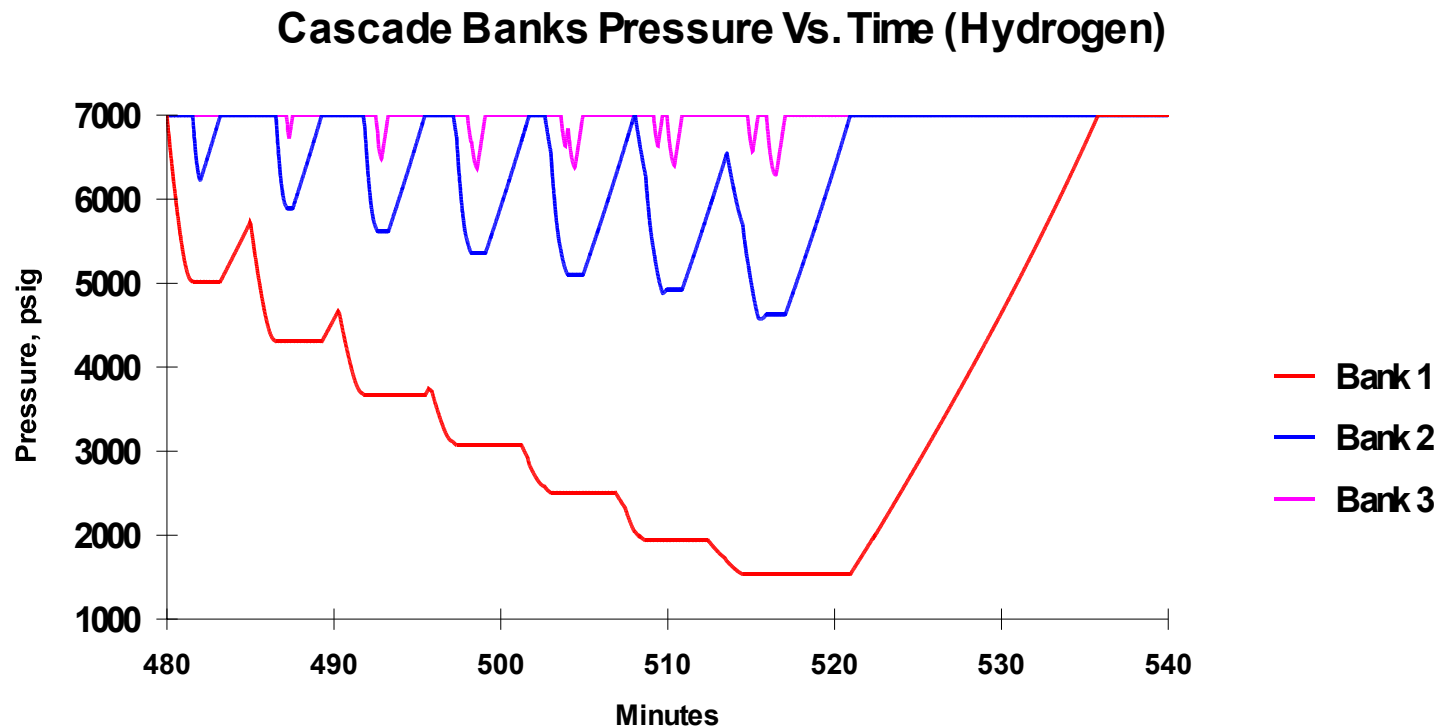
- Net present value
- Payback (simple and discounted)
- Rate of return solver

Cascade Pressure



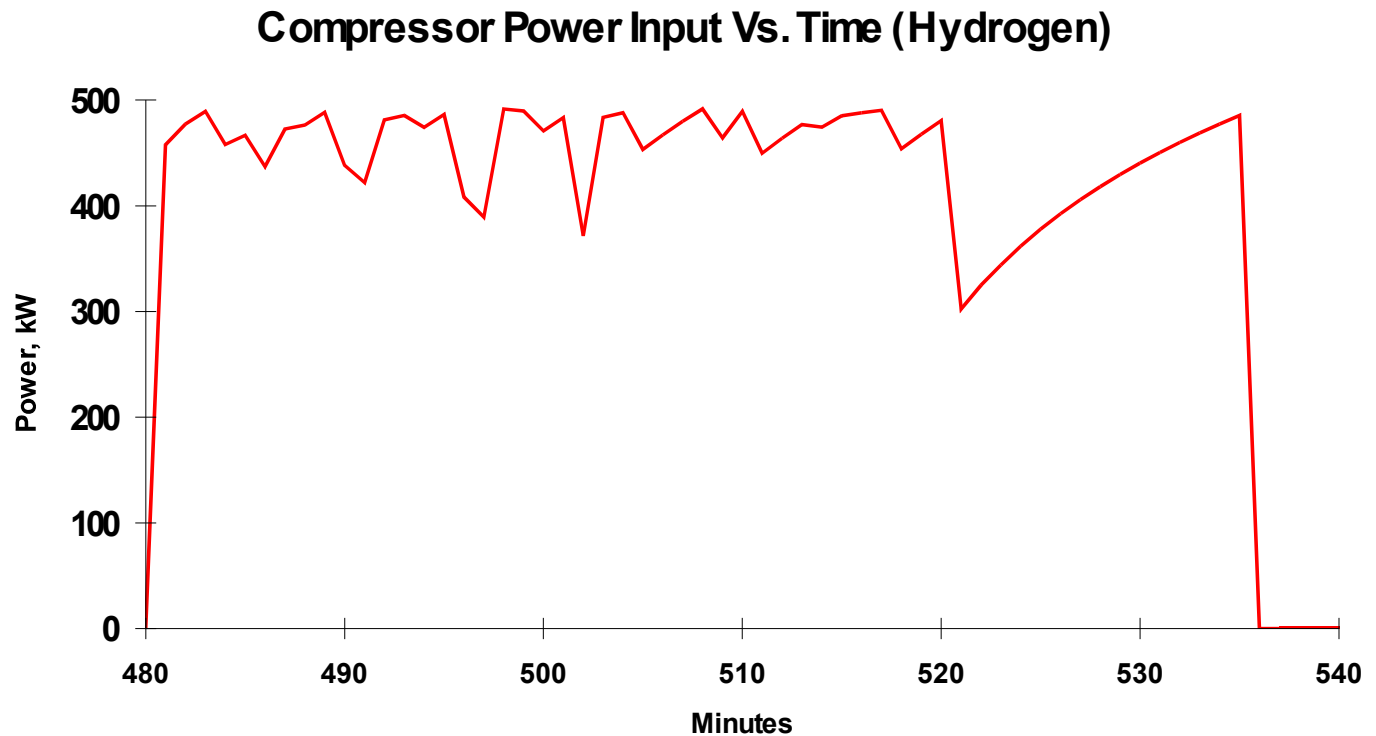
Cascade Pressure

One Hour



Compressor Power

One Hour

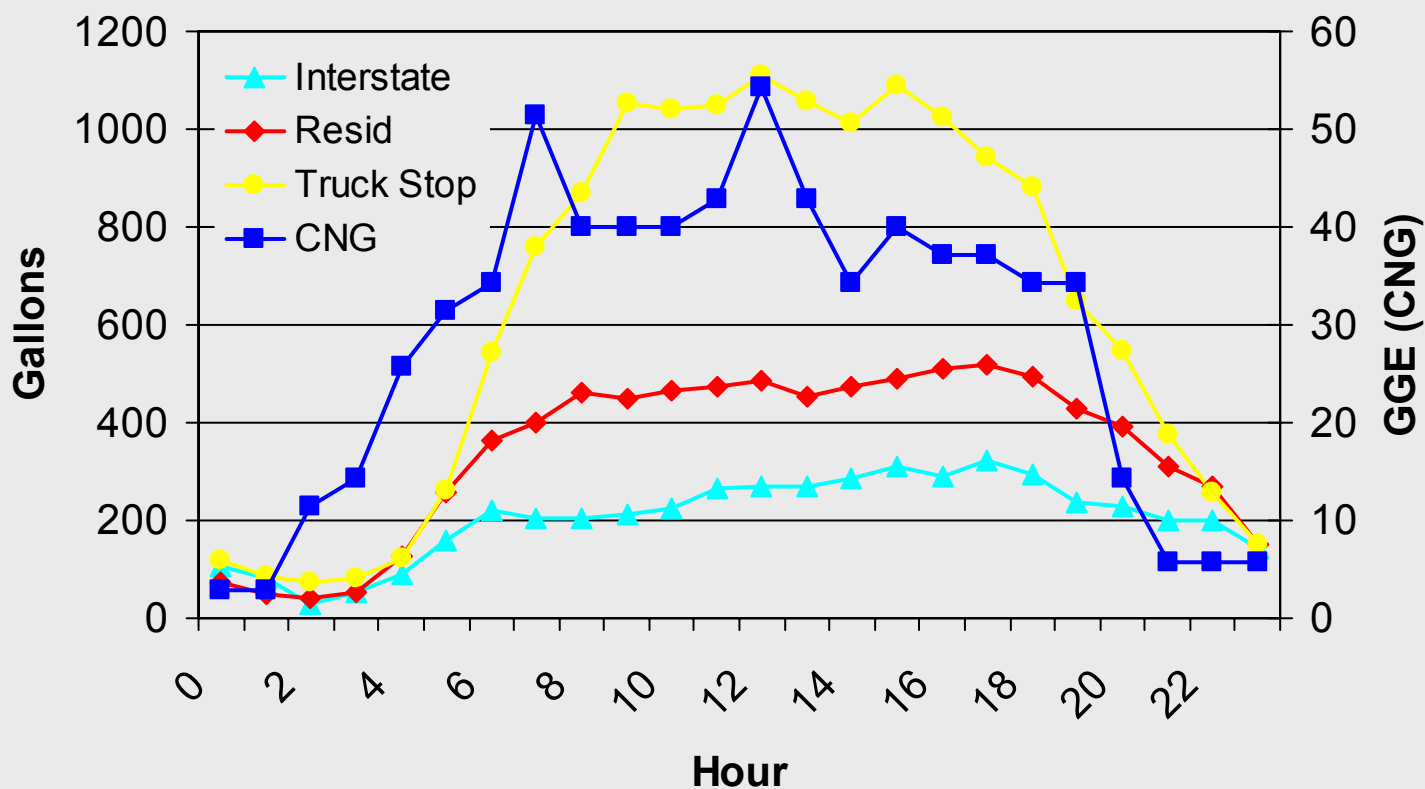


Sample Analyses

- > Different demand profiles normalized to 1200 kg per day
 - Gasoline data courtesy of ConocoPhillips
 - > Truck stop, interstate station, large residential station
 - Compressed natural gas (CNG) station

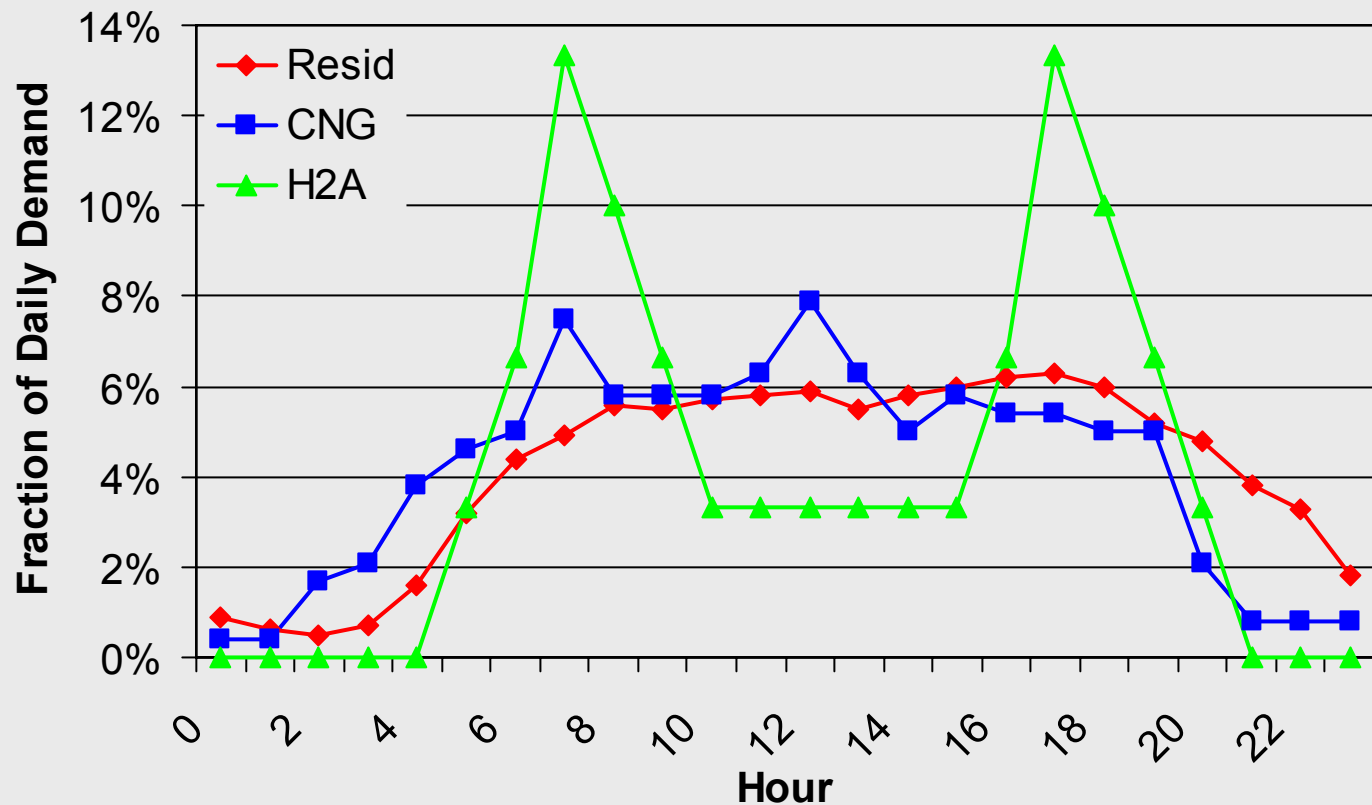
Station Demand Profile

- > Gasoline: 5000 to 15000 gal/day
 - Average station is about 3300 gal/day
- > CNG: 700 gal/day



H2 Station Demand Profile

- > Residential, CNG, and H2A profiles normalized to 1200 kg/day

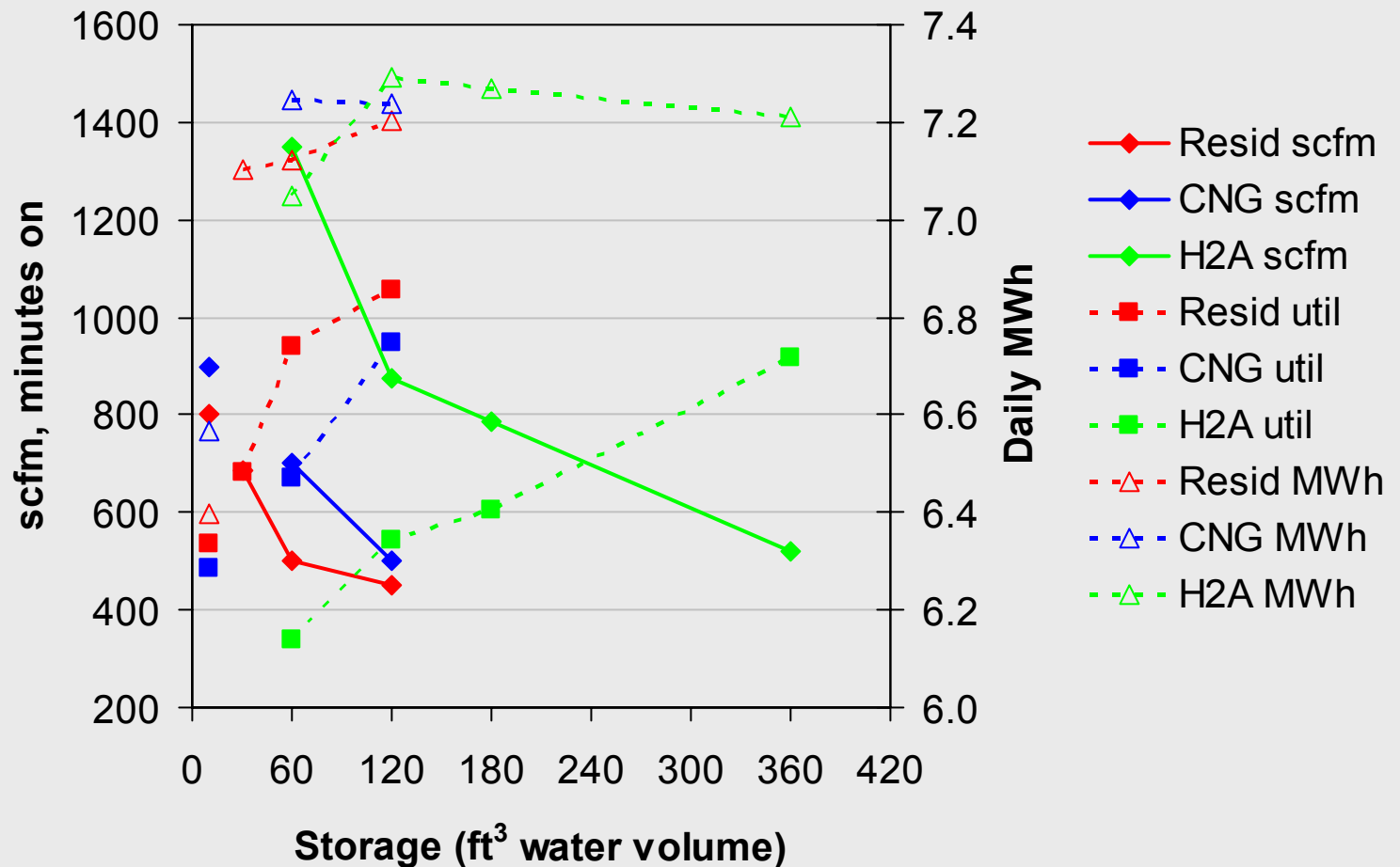


H2 Station Sizing

- > Used CASCADE to determine required compressor output for various cascade capacities for each load profile
 - Single bank cascade (10 ft³ water volume)
 - Three bank cascades
 - > 30 to 360 ft³ water volume
- > All simulations used 3-2-1 capacity ratios
 - Low bank (first used by vehicle) the largest
 - Marginal performance improvement relative to 1-1-1 ratio

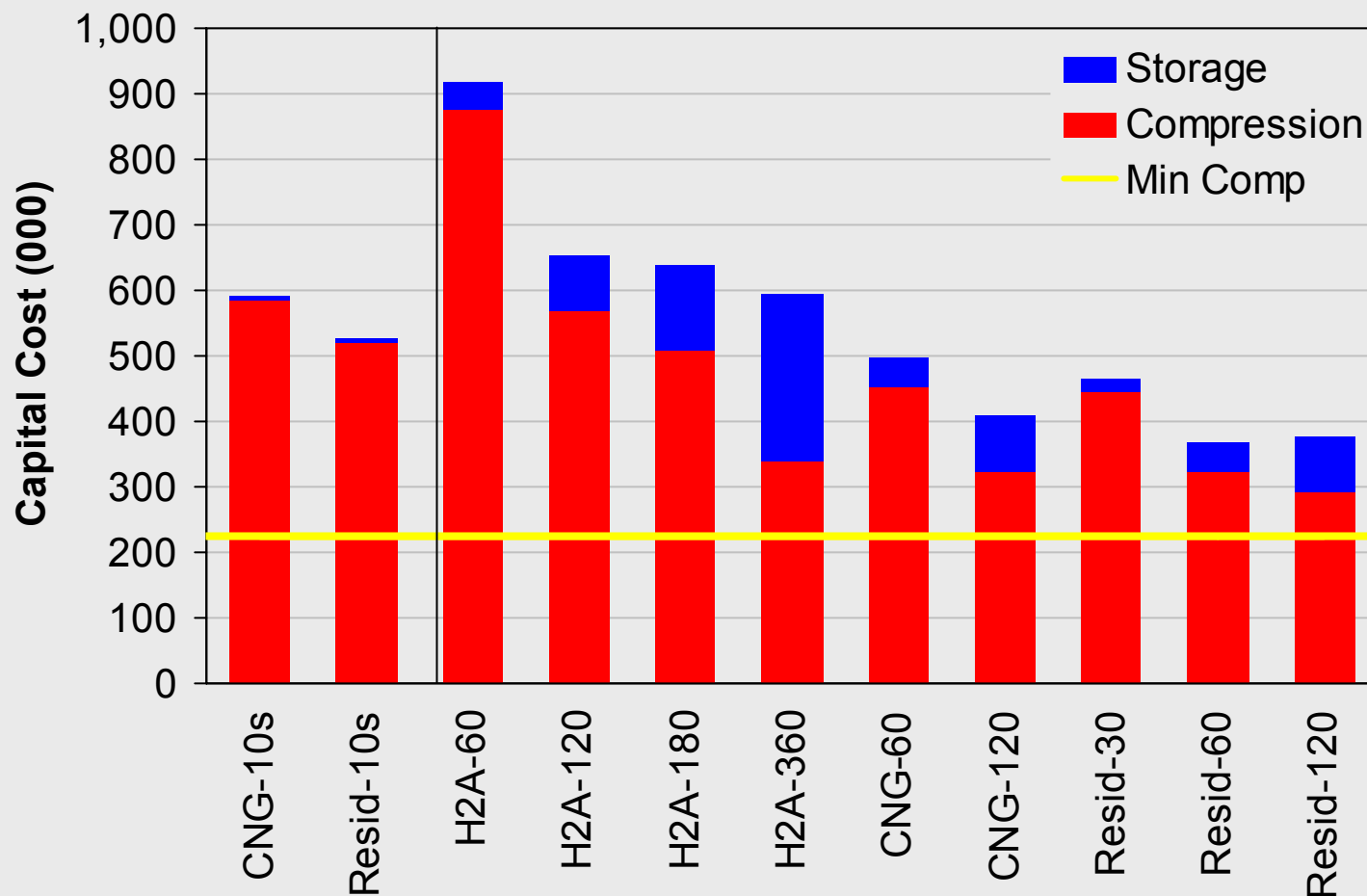
Compressor-Storage Relation

Compressor Size, Utilization, and Energy



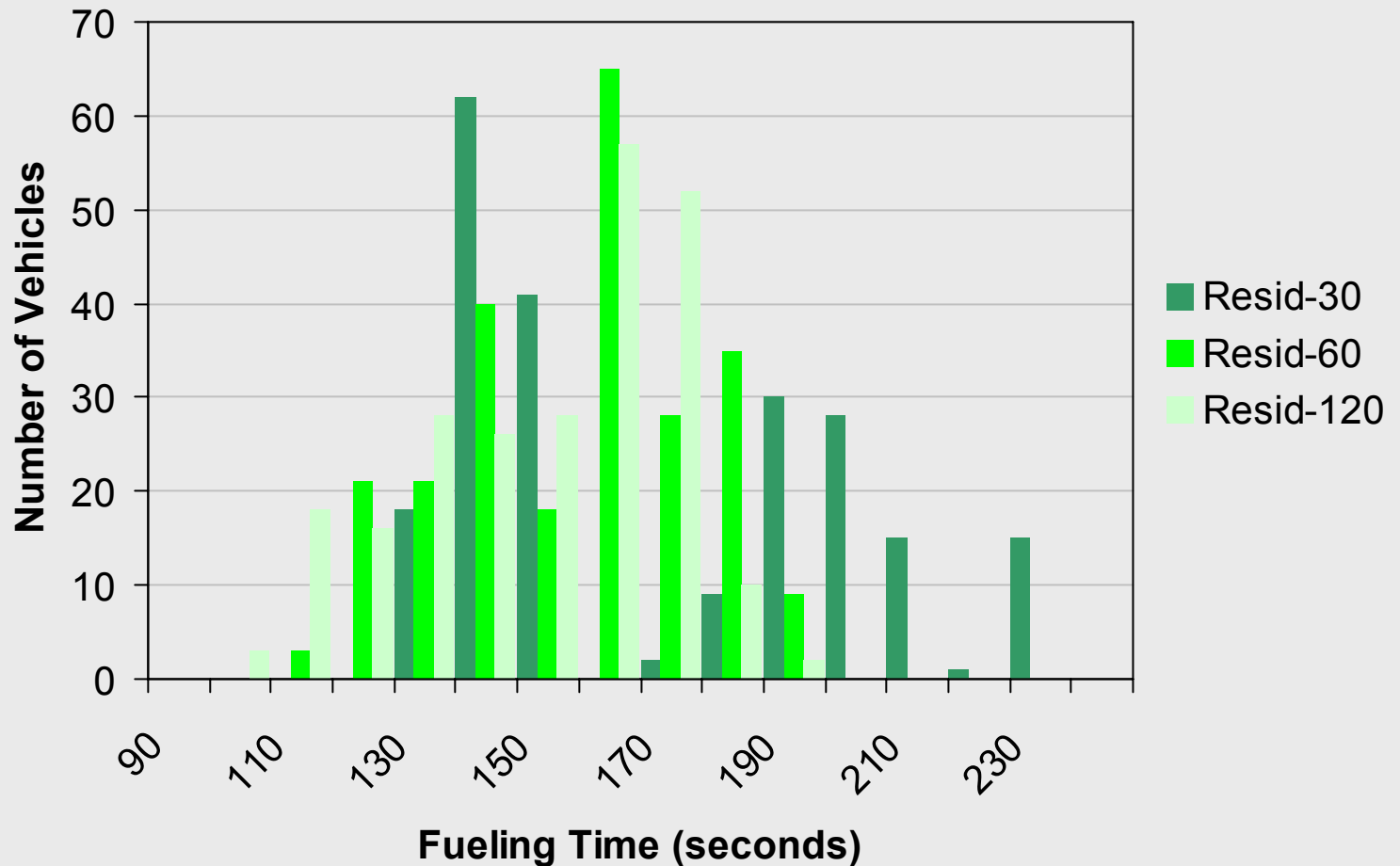
Compressor-Storage Costs

H2A Assumptions: \$4500/(kg/hr), \$818/kg



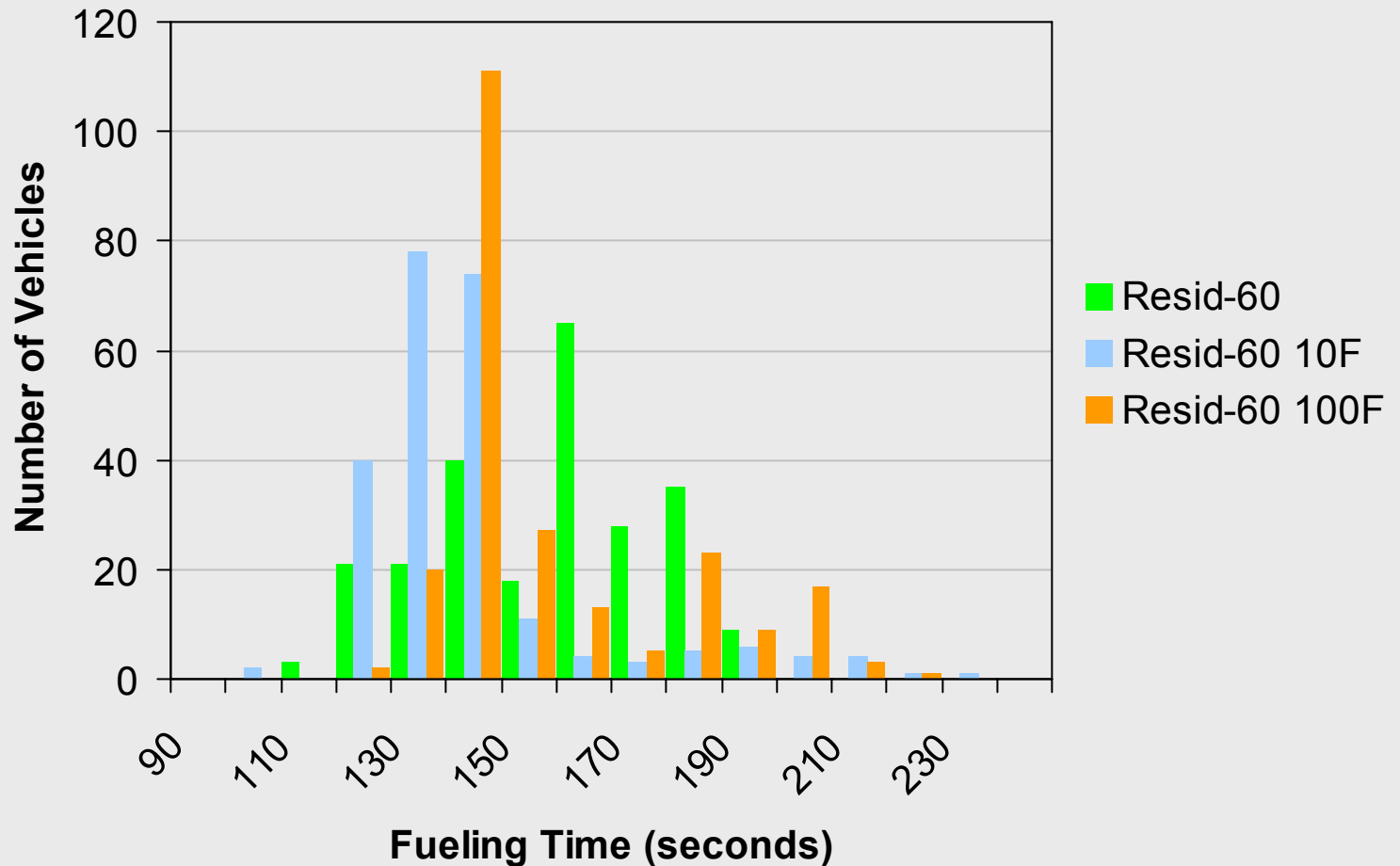
Vehicle Fueling Times

Resid Profiles



Vehicle Fueling Times

Resid Profiles, Ambient Temperature Effects



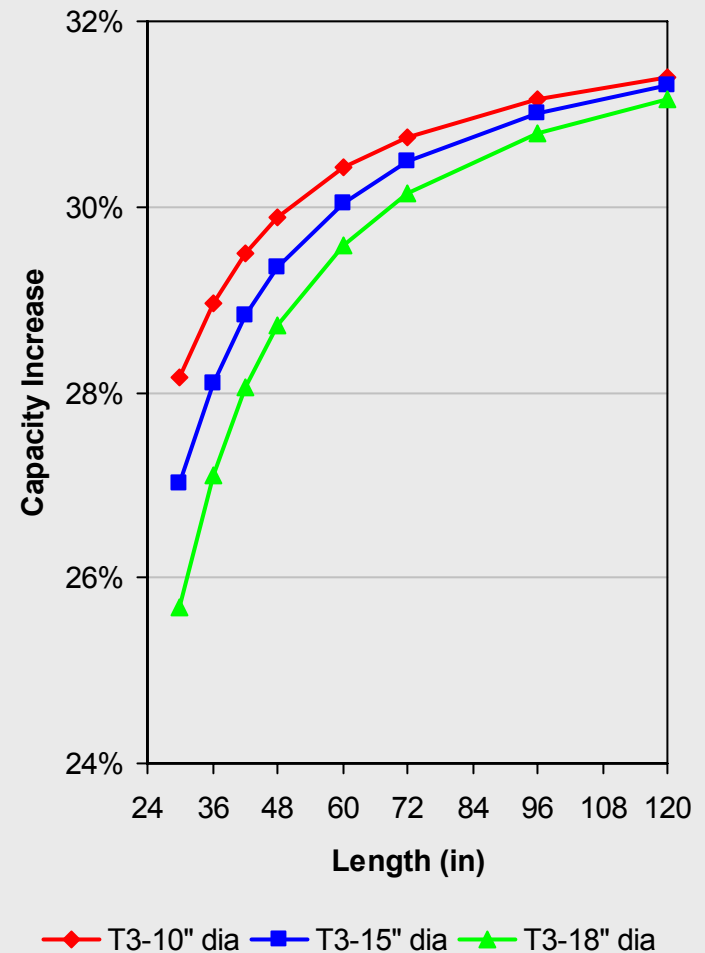
Vehicle Fueling Times

	CNG 10s	Res 10s	CNG 60 120	Resid 30 60 120
Mean	243	264	136 144	173 149 145
σ	34	28	22 24	42 19 20

	CNG		
	60	60: 10F	60: 100F
Mean	136	134	148
σ	22	21	23

70 MPa Considerations

- > Diminishing returns for vehicle storage
 - 35 to 70 MPa yields 67% increase for gas properties
 - Same outer volume constraint: 25 to 31%
- > Increased specific costs of fueling equipment
- > Difficulties in limiting vehicle tank temperature during fueling



Future Work

- > Complete configuration analyses
- > Complete cost data collection
- > Perform economic analyses
- > Examine additional tradeoffs
 - Cryo pump vs. compressor
 - Under ground vs. above ground
 - Advanced composites vs. steel
- > Potential inclusion of impacts of 70 MPa fueling scenarios

Summary

- > CASCADE H2 PRO is designed to be a simple, yet powerful, tool for:
 - Assisting designers in analyzing complex station equipment interactions
 - Providing valuable performance and economics assessments
- > Version 1.0 is currently undergoing testing and review
 - Expected to be available for purchase in the second half of 2006
- > Initial analyses indicate some H2A assumptions may need revision

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